ADJUSTING MILK REPLACER INTAKE DURING HEAT STRESS AND NON-HEAT STRESS AS A MEANS OF IMPROVING DAIRY CALF PERFORMANCE

A Thesis

by

THERESA MARIE CHAVEZ

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Animal Science

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Approved by:

Co-Chairs of Committee,	Glenn Holub
	Tryon Wickersham
Committee Member,	Jason Sawyer
Head of Department,	H. Russell Cross

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ABSTRACT

Adjusting Milk Replacer Intake During Heat Stress and Non-heat Stress as a Means of Improving Dairy Calf Performance.

(May 2011)

Theresa Marie Chavez, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Glenn Holub
Dr. Tyron Wickersham

The objective of this study was to evaluate the effects of heat stress and varying levels of milk replacer on dairy calf performance. Holstein bull calves ≤ 2 d of age were randomly assigned housing, outside under a covered area, heat stress (HS), or inside a controlled environment, non-heat stress (NHS), to test for heat stress effects on growth. Calves were also assigned to one of three feeding strategies: increasing amounts of milk replacer from 1.1% body weight (BW) to 1.5% BW (INC), constant at 1.1% BW (CON), or decreasing from 1.6% BW to 1.2% BW (DEC), adjusted weekly, commencing on day 9 of feeding and ending on day 40. Milk replacer amounts were adjusted twice weekly after weighing. Calves had ad libitum access to commercial starter feed and water. Starter intake, water intake, and fecal score (1 to 4) were recorded daily. Respiration rates and rectal temperatures were recorded twice daily at 0600h and 1800h.

Average daily gain was greater ($P < 0.01$) for NHS (0.79 ± 0.03 kg/d) compared to HS (0.66 ± 0.03 kg/d) The NHS calves consumed more starter ($P < 0.01$) than HS

(1.77 vs 1.16 ± 0.06 kg/d. Water consumption averaged 3923 ± 105 mL/d for HS which was greater ($P < 0.01$) than NHS (2338 ± 105 mL/d).

No significant differences were observed among the feeding treatment groups for weight gain ($P = 0.73$). Milk replacer levels had a significant impact ($P < 0.01$) on the amount of calf starter consumed with CON consuming the most (1.64 ± 0.07 kg/d), followed by INC (1.44 ± 0.07) and DEC consuming the least (1.34 ± 0.07 kg/d). Water intake was also significantly impacted by milk replacer levels ($P < 0.01$). Calves in the DEC group consumed the least amount of starter, and consumed more water (3657 ± 129 mL/d) than both INC calves (3119 ± 129 mL/d) and CON calves (2614 ± 129 mL/d).

Overall, housing has an impact on growth in neonatal dairy calves; however, milk replacer levels did not impact growth of the calves.

DEDICATION

This thesis is dedicated to my family. They have supported and guided me with so many aspects throughout my life. I want to thank my parents for their unyielding love, support, and sacrifices to provide their children with amazing opportunities. Dad, your love, strength (especially emotionally and spiritually), work ethic, determination, and character have served as a daily example for everyone around you. I try my best to follow your lead. Mom, you are never more than a phone call away. Your love and words of encouragement always provide comfort, even from miles away. Cynthia, your determination has always inspired me and spending time talking at the kitchen counter are some of my favorite times with you. Marissa, you always seem to know what to do in any situation, and our conversations and visits are always great. My favorite brother, Rene, your charisma and loyalty are incredible, and you always get me to laugh no matter how determined I am not to do so.

I thank God for blessing me with an incredible family. Over the years, I believe we have created an amazing bond which will continue to strengthen regardless of the years or miles. I love you.

ACKNOWLEDGEMENTS

A special thank you to all those who helped me throughout this entire process and made an impact no matter how great or small throughout my academic career. Thank you to the students who assisted with data collection, especially those who extended their friendship (Andrew, Andrea, Natasha, and Kelly B). Also, I extend my appreciation to the graduate students who volunteered their time to help with the project. A special thank you to Dr. Glenn Holub, you provided encouragement, knowledge, and constructive criticism throughout everything. I am truly grateful for your guidance and support. Dr. Tryon Wickersham, thank you for providing me with my first experiences with research in ruminant nutrition. I appreciate your willingness to provide advice and offer your expertise. Dr. Jason Sawyer, your advice and input are always appreciated. Thank you for taking the time to helping me to understand along the way. I also wish to thank Dr. Danielle Harris for words of wisdom and providing a unique assistantship. I also want to recognize Michelle who has known me throughout my entire college career, thanks for sharing in the laughter, tears, and random adventures which make our friendship stronger and create memories which will last a lifetime. Also, my friends in Animal Science, especially Robynne, Chelsey, Kelly W, and Jamie, I always enjoy visiting with you in and out of Kleberg. To everyone I met in Brazil, Ana Paula, Ivo, Beryk, Fernanda and many more, thank you for the warm welcome, incredible memories, and making it one of the best experiences.

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CHAPTER I

INTRODUCTION

Recent years have seen an increase in the number of dairy farms moving into Texas and New Mexico. How this shift in location, particularly environmental conditions, affects calf rearing has not been widely researched. Therefore, research needs to be conducted to elucidate the effects of heat stress on dairy calves.

The Southern United States is divided into several climate regions, with areas of Texas and New Mexico classified as subhumid and semiarid. Cattle raised in this region are subjected to high heat and humidity during the summer months. The stress created in this environment leads to physiological responses from the animal and a reduction in productivity. In dairy cattle, heat stress consistently results in reduced DMI (West, 1994) and increased DM digestibility (Lippke, 1975) and decreased rate of gain (Ray, 1989). Heat stress causes an increase in maintenance requirements while reducing growth and feed efficiency. Though the effect of heat stress is generally greater in older, milk producing cattle, the development of calves is also affected. Calves physiologically respond to temperatures above 32.2°C and begin acclimation after four to five hours in temperatures greater than 37.7°C. As temperatures begin to exceed 26.7°C the calves' ability to maintain thermeostasis and ability dissipate heat begins to become

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This thesis follows the style of Journal of Dairy Science.

overwhelmed. Calves have increased heart rates when temperatures increase from 32.2°C and 37.7°C (Neuwirth, 1979). Continued exposure to high heat, 37.7°C, for at least six hours, causes a significant increase in cortisol levels, indicating stress (Neuwirth, 1979). Bohmanova et al. (2007) reported that lactating cows experience heat stress at a temperature humidity index (THI) of 72. While calves are not subject to the stresses of lactation, they do need to grow rapidly at an early age and increased THI may have an effect greater than initially considered.

Heat stress will likely hinder growth and feed efficiency further and increase maintenance requirements. It is generally believed that rearing calves in a heat stress environment reduces growth rate, starter intake, delays weaning, and reduces feed efficiency.

Dairy calves are typically given a restricted amount of milk replacer powder, ~1.0% of BW daily, or 10% BW in liquid milk. Many dairy producers feed unmarketable milk containing antibiotics to their calves and do not know the nutrient makeup of the milk or antibiotic levels in the milk, nor the exact amount that is fed to calves daily. Restricting milk intake generally results in low nutrient availability (Egli and Blum, 1998; Appleby et al. 2001), poor health (Huber et al., 1984) and reduced productivity of dairy calves (Pollack et al. 1993). Recently, enhanced feeding programs have been promoted by dairy calf nutrition companies in an effort to wean heavier calves at an earlier age. Heifers are being fed for accelerated growth to decrease age at first calving; possibly reducing some of the cost of raising replacement heifers which accounts for approximately 20% of dairy farm expenses (Heinrichs, 1993). Jasper and

Weary (2002) found that when calves were allowed ad libitum consumption of milk, they consumed almost double compared to those fed conventional amounts. Though they consumed less starter and hay prior to weaning, there was no difference between the amount of solid food consumed and those fed conventional amounts during the post-weaning. They reported calves feed ad libitum consumed 89% more milk and weighed 63% more than those feed conventional amounts. Ad libitum fed calves remained healthier as well. Barlett et al. (2006) found that calves offered 1.75% BW had increased ADG and increased gain to feed while decreasing the percent protein and urea nitrogen in plasma when compared to calves offered 1.25% BW. They did not see a significant difference in fecal scores between these treatments. Results show that calves given more milk had more energy available for growth. Hammon et al. (2002) found reduced blood cortisol levels in calves feed ad libitum, indicating lower stress levels. However, ad libitum consumption of milk can lead to decreased consumption of starter. Reduced starter feed consumption is associated with poor post-weaning performance due to delayed ruminal development (Baldwin et al. 2004).

Bascom et al. (2007) concluded that feeding bull calves a 20% protein, 20% fat milk replacer at 1.5% BW is not advisable as the growth of these calves was inferior to calves feed higher levels of protein and not as expected in thermoneutral conditions. This suggests that nutrient requirements, specifically maintenance requirements for calves may be underestimated. Therefore, modifying diets of neonatal calves may lead to improved health while reducing cost of development.

CHAPTER II

REVIEW OF THE LITERATURE

Multiple factors influence the growth and development of neonatal calves including nutrition, and environment. Understanding and managing for these factors will enable calves to reach their genetic potential. Adjusting nutrition and environment to best meet the needs of the rapidly growing animals should be done to improve the performance in terms of health and growth, while being economically feasible. Dairy calves, specifically replacement heifers, have historically been reared in the cooler regions of the United States with little knowledge of the effect of heat stress on the neonatal calves and the role of nutrition in coping with heat stress.

Heat Stress

Climatic conditions throughout the United States vary from region to region. Parts of Texas and New Mexico are classified as semiarid or subhumid with cattle raised in this region subjected to high heat during the summer months. Stress resulting from the environment leads to physiological responses by the animal and a reduction in productivity. Climatic variance requires agricultural producers to understand their environment to achieve maximum production. In the livestock industry, this often entails utilizing genetics or breeds capable of thriving in a given climate, as well as providing proper housing and nutrition to reduce the amount of climatically induced stress. Genetically, the dairy industry is limited give the heavy reliance on Holstein

Friesian (Holstein). Holsteins are well suited for the cooler climate of the northern regions; however, they face challenges associated with the warmer southern region of the country. A better understanding of the environment and its impact upon nutritional requirements are needed to best meet the demands of high producing animals. Furthermore, understanding this interaction might improve performance of dairy calves, specifically replacement heifers, which have historically been reared in cooler regions of the United States.

Homeothermy allows animals to maintain a constant body temperature through heat loss or production in order to prevent hypothermy or hyperthermy (Albright and Allistion, 1976). Animals have a range of environmental temperatures at which they are able to maintain themselves and produce efficiently with few physiological changes. This range of temperature is referred to as the thermoneutral zone (TNZ); a "zone within which compensatory responses by the organism are absent" (Bianca, 1976). The TNZ for calves is between 15 and 25°C, depending on age, feed intake, subcutaneous fat, and hair coat (NRC, 2001). The range of temperature is also influenced by stage of life and production level (Figure 1). Calves physiologically respond to temperatures above 32.2°C and begin acclimation after 4 to 5 hours in temperatures greater than 37.7°C. As temperatures begin to exceed 26.7°C, the calves' ability to maintain thermeostasis and dissipate heat begins to become overwhelmed. When strain is detected, biological changes by the animal begin to adapt to the changing environment. The upper critical point is commonly defined as the point at which there is an increase in evaporative heat loss through the skin (sweating) or respiratory tract (panting) (Berman, 1968; Bianca,

1976) around 26 ºC in cattle (Silanikove, 2000). In one particular study, heat stress began to be apparent when temperature exceeded 32.2°C at 60% relative humidity compared to lower ambient temperatures (Neuwirth, 1979). Younger animals have a more narrow range for thermal comfort compared to adults (Bianca, 1976). Once outside of this temperature range, animals must elicit the use of various defense mechanisms to heat or cool themselves.

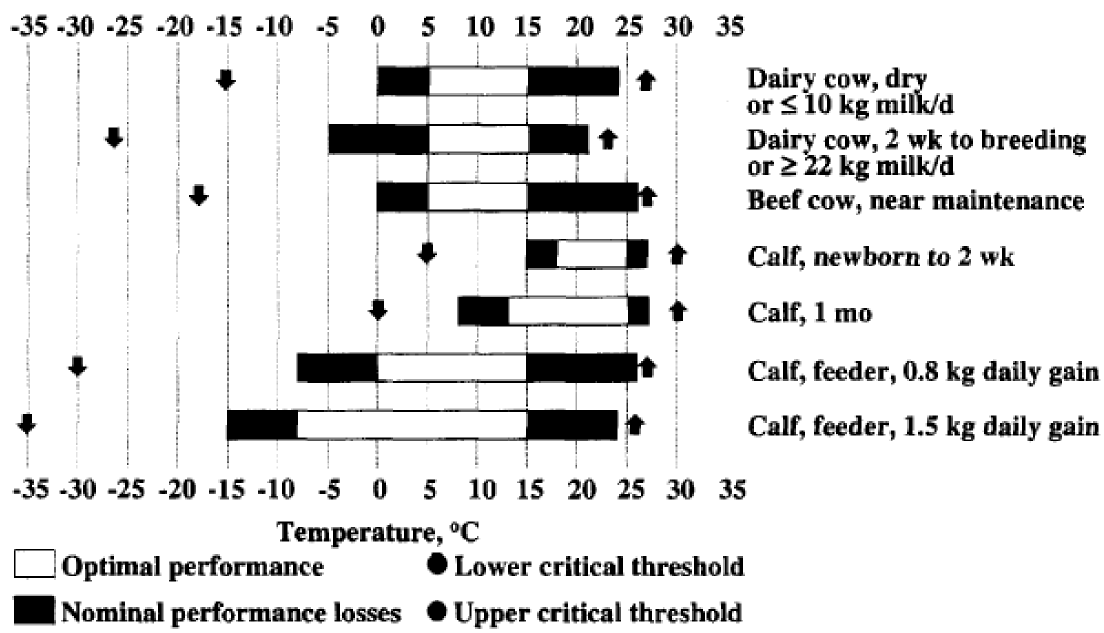
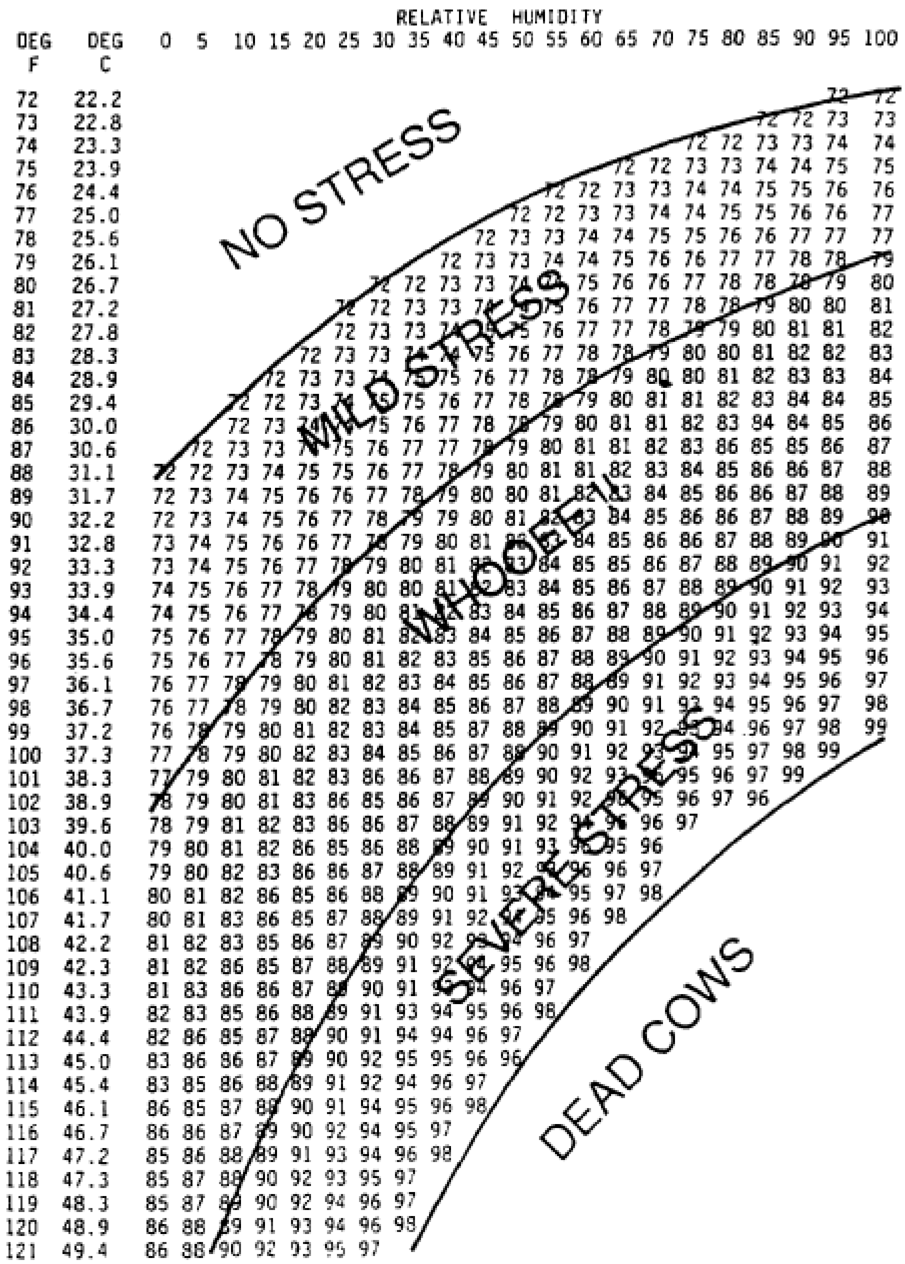


Figure 1. Range of temperatures for optimal performance in cattle. (Hahn, 1999)

Finch (1986) identified environmental conditions which cause stressful environments: high ambient temperature, direct solar radiation, indirect solar radiation, wind speed, and humidity. These factors all play a role in the level of heat stress imposed upon an animal, as well as its ability to dissipate heat and maintain a consistent body temperature. Heat stress is defined as the “demand made by the environment for heat dissipation” (Silanikove, 2000), while strain is considered “internal displacement from basal state caused by external stress (Finch, 1986). Bianca (1976) identified differing degrees of strain: thermal indifference, mild heat, moderate heat, and severe heat. At moderate heat, production levels may begin to be affected while severe heat may result in death. Most mammals die when core body temperatures approach 42 to 45ºC (Bianca, 1968). The dairy industry has used THI to evaluate the degree of heat stress in dairy cattle. This measure of ambient temperature and humidity indicates levels of stress ranging from THI values of 72 to 99 (Figure 2). Values below 72 are considered non-stressful while values above 99 are believed to result in death of the cow (Armstrong, 1994). In order to avoid reaching these extreme temperatures, mammals elicit various adaptation responses to aid in regulation of core body temperature.



DEG F	DEG C	RELATIVE HUMIDITY																				
		0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
72	22.2																				72	72
73	22.8																		72	72	73	73
74	23.3																72	72	73	73	74	74
75	23.9														72	72	73	73	74	74	75	75
76	24.4												72	72	73	73	74	74	75	75	76	76
77	25.0											72	72	73	73	74	74	75	75	76	76	77
78	25.6										72	73	73	74	74	75	75	76	76	77	77	77
79	26.1									72	73	73	74	74	75	76	76	77	77	78	78	79
80	26.7							72	72	73	73	74	[illegible]	75	76	76	77	78	78	78	79	80
81	27.2						72	72	73	73	74	[illegible]	75	76	77	77	78	78	79	80	80	81
82	27.8						72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82
83	28.3					72	73	73	74	74	75	76	77	78	78	79	80	80	81	82	82	83
84	28.9				72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84
85	29.4			72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
86	30.0			72	73	74	[illegible]	75	76	77	78	78	79	80	81	81	82	83	94	84	85	86
87	30.6		72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	86	85	85	86	87
88	31.1	72	72	73	74	75	75	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88
89	31.7	72	73	74	75	76	76	77	78	79	80	80	81	82	83	84	85	86	86	87	88	89
90	32.2	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
91	32.8	73	74	75	76	76	77	78	79	80	81	[illegible]	[illegible]	84	85	86	86	87	88	89	90	91
92	33.3	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92
93	33.9	74	75	76	77	78	79	80	80	81	82	83	84	85	86	87	88	89	90	91	92	93
94	34.4	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94
95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	35.6	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96
97	36.1	76	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95	96	97
98	36.7	76	77	78	79	80	82	83	84	85	86	87	88	89	90	91	92	94	95	96	97	98
99	37.2	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	[illegible]	94	96	97	98	99
100	37.3	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	[illegible]	95	97	98	99	
101	38.3	77	79	80	81	82	83	86	86	87	88	89	90	92	93	[illegible]	95	96	97	99		
102	38.9	78	79	80	81	83	86	85	86	87	89	90	91	92	[illegible]	95	96	97	96			
103	39.6	78	79	81	82	83	86	86	87	88	89	91	92	94	96	96	97					
104	40.0	79	80	81	82	86	85	86	88	89	90	91	93	96	95	96						
105	40.6	79	80	82	83	86	86	87	88	89	91	92	[illegible]	96	96	97						
106	41.1	80	81	82	86	85	86	88	89	90	91	93	[illegible]	95	97	98						
107	41.7	80	81	83	86	85	87	88	89	91	92	[illegible]	95	96	98							
108	42.2	81	82	83	85	86	87	89	90	92	93	94	96	97								
109	42.3	81	82	86	85	87	88	89	91	92	94	95	96	98								
110	43.3	81	83	86	86	87	88	90	91	[illegible]	94	96	97									
111	43.9	82	83	85	86	88	89	91	93	94	95	96	98									
112	44.4	82	86	85	87	88	90	91	94	94	96	97										
113	45.0	83	86	86	87	89	90	92	95	95	96	96										
114	45.4	83	85	86	88	89	91	92	94	96	97											
115	46.1	86	85	87	88	90	91	94	95	96	98											
116	46.7	86	86	87	89	90	92	94	95	97												
117	47.2	85	86	88	89	91	93	94	96	98												
118	47.3	85	87	88	90	92	93	95	97													
119	48.3	85	87	89	90	92	94	96	97													
120	48.9	86	88	89	91	93	94	96	98													
121	49.4	86	88	90	92	93	95	97														

Figure 2. Temperature-humidity index used to determine heat stress in dairy cattle. (Armstrong, 1994)

Adaptation Responses

Physiological, hormonal, and behavioral responses by the animal are used to help the animal maintain its body temperature. The environment of any animal impacts their utilization of nutrients and performance. Ambient temperature and humidity both impact the comfort of the animal. Temperature humidity index (THI) combines both temperature and humidity which may be used to evaluate environmental conditions. Calves have increased heart rates when temperatures increase to 32.2°C and 37.7°C (Neuwirth, 1979). Continued exposure to high heat, at or above 37.7°C for at least six hours, causes a significant increase in cortisol levels, indicating stress (Neuwirth, 1979). Bohmanova et al. (2007) reported that lactating cows experience heat stress and decrease milk production at a temperature of 22.2°C and THI ≥ 72. While calves are not subject to the stresses of lactation, they do need to grow rapidly at an early age and increased THI may have an effect greater than initially considered. Extreme heat is not required for differences in performance to be noted. It has been observed that calves housed outdoors in temperatures around 2.9ºC had higher body weight and average daily gain compared to calves housed indoors in temperatures at approximately 10ºC. Though they had a higher maintenance requirement, Richard et al. (1988) did not observe calves increase milk or starter consumption in response to the demand of cold weather. These calves demonstrated a significantly greater ADG postweaning than those in warmer environments

The most visual responses to thermal heat stress in cattle are sweating and panting; both are controlled mechanisms which allow homeotherms to regulate body temperature. Increased sweat production occurs in an effort to increase evaporative heat loss. In severe thermal stress, animals may even use saliva or nose secretions to help moisten their body in an effort to increase cooling (Silanikove, 2000). While sweating does assist in heat dissipation, panting is a better indicator of stress in cattle as sweating may begin to occur between 12 and 14ºC, even though it is still within their TNZ (Silanikove, 2000). As an animal pants, it allows more air to pass through the respiratory tract to facilitate heat dissipation. It also helps cool blood passing through the nasal region, where most heat exchange takes place (Robertshaw, 2006), allowing brain temperature to remain lower than core body temperatures (Robertshaw and Daniel, 1983). Observing respiration rate is a fairly easy method for producers to monitor thermal stress in their livestock. In cattle, approximately20 breaths/min is considered a basal level. As this number surpasses 40 breaths/min, panting is utilized to dissipate heat; in severe heat, this number may reach 150 (Silvanikove, 2000). In 1999, a study by Hahn identified 21.3ºC as the ambient temperature at which respiratory rate increases at a rate of 4.3 breaths/minute per degree using a baseline of 60 breaths/min. Monitoring respiration rate, especially during periods of thermal stress, can give an indication of the level of strain on the animal. Another method of evaluating thermal stress would be obtaining rectal temperature. Lemerle and Goddard (1986) indicated that using respiration rate and rectal temperature may be better indicators than pulse rate when trying to determine thermal stress. This is due to the fact that pulse rate is not influenced by thermal season. Elevated core body temperature occurs when ambient temperature rises too quickly for an animal to dissipate additional heat. *Bos indicus* cattle have a higher rectal temperature than *Bos taurus*, reflecting the difference in heat tolerance capabilities. In cattle, and most other livestock species, a rise in rectal temperature as little as 1ºC is sufficient to negatively affect performance (Silvanikove, 2000; McDowell et al., 1976). Such rises in temperature are more severe during heat stress because a rise of only 3 to 6ºC in body temperature is lethal; however, for cold stress, there is a difference of 15 to 25ºC before lethal levels are reached (Bianca, 1976).

Increases in body temperature are seen during the day. Throughout the day, cattle accumulate heat externally from solar radiation, and internally from metabolism, which is stored until temperatures drop in the evening, allowing the stored heat to dissipate to the surrounding environment (Finch, 1986). When temperatures fall below 21ºC for a minimum of 3 to 6 hours, animals are capable of dissipating heat from the day (Silanikove, 2000). Such heat dissipation is necessary, and often sufficient to allow livestock to recover from the stress associated with the high ambient temperatures. However, especially in the southern regions of the Unites States, there may be periods when several days of elevated temperatures persist even in the evening, placing strain on livestock. During periods of chronic heat stress, 3 or 4 d are needed before acclimation to these increased temperatures take place (Hahn, 1999).

Water

Body temperature of livestock is not solely dependent upon environmental temperature but also affected by feed quality and quantity, and intake of water (Finch, 1986). Water requirements may be met by metabolic water, water found in feed, and drinking water (Winchester and Morris, 1956; NRC 1981). Water intake by the animal may be affected by several factors: level of feed intake, physical form of diet, accessibility, and temperature of the water (NRC, 1981). Water availability is necessary to prevent dehydration, especially for an animal which relies on evaporation to alleviate its heat load. It is essential that water supply not be overlooked. This includes calves receiving milk as part of their nutritional requirements; the water content of milk is not sufficient to meet the water needs of a calf. As temperatures reach 4.4ºC, water intake in cattle increases. A 45 kg calf will consume approximately 2.6 liters of water at 4.4ºC compared to 6.1 liters of water as temperatures approach 32ºC (Winchester and Morris, 1956). When evaluating calves with ad libitum access to water, it was reported these calves consumed an average of 41.33 kg of water during the initial 4 wks of life (Kertz et al. 1984).

Influence of Production Level

External factors play a significant role in influencing body temperature, and heat dissipation; however, internal factors must be considered as well. As production increases, so does the animal's need for nutrients which leads to increased metabolism. Heat is produced during metabolism of feed; this heat must be released into the environment if homeothermy is to be maintained (McArthur and Clark, 1988). For example, a cow which produces 10 kg milk/d will produce 17,000 kcal of heat energy, while another producing 50 kg milk/d will produce 36,000 kcal of heat energy (Bianca, 1976). This illustrates that as production increases, so does heat load. As seasons change and ambient temperatures begin to rise, livestock induce heat dissipation mechanisms and reduce feed intake (Hahn, 1999). When ambient temperatures increase, cows will consume feed and produce milk at a stable, but lowered level when compared to those in cooler temperatures (West, 1999). Likewise, a lactating cow will decrease feed intake at lower temperatures than non-lactating cows (21 compared to 32ºC) (Winchester and Morris, 1956). Currently, there is little information regarding how heat stress specifically affects young growing dairy calves.

Housing

Aside from providing water, livestock should be provided with housing which would assist in reducing thermal stress. When no housing or shade is provided, the animal will attempt to reduce its exposure to solar radiation by positioning itself vertically with the sun (Hafez, 1968). Housing types vary depending on type of production or operation. Type of housing is a part of the environmental conditions which affects the incidence and severity of scours, growth, and intake in young calves as Quigley et al. (1995) indicated. Traditionally, calves are housed individually in hutches to prevent the spread of disease and provide shelter; however, it has been shown that calves housed in hutches have higher average body temperatures than calves reared in shaded and cool shaded areas (Spain and Spiers, 1996). This may reflect the solar radiation retained by plastic hutches (Broucek, 2009). Hutch reared calves also had lower IgG concentrations, indicating a response to heat stress (Stott, 1976). Macaulay et al. (1995) concluded there are differences between types of hutches: polyethylene domes, wooden hutches, and polymer hutches. Tympanic temperatures for neonatal calves were monophasic with maximums at 1200 to 1800 h and minimums at 0600 to

0900. However, these results come from a cooler, northern climate during the months of September to December.

More research is needed to understand how this shift in location, particularly environmental climate, will affect calf rearing.

Heat stress hinders growth and feed efficiency and increases maintenance requirements. Rearing calves in a heat stress environment may result in reduced growth rate, reduced starter intake, delayed weaning, and reduced feed efficiency.

Nutrition

Nutrition impacts every aspect of an animal's life from conception to consumption. Proper nutrition is necessary to ensure livestock are able to reach full genetic and production potential. Feeding strategies are modified and feedstuffs changed to maximize growth and efficiency. Managing diets also affects production costs. Achieving a balanced diet is of particular importance in the dairy industry, especially in calves. Dairy calves are raised through intensive handling and care compared to beef calves. Calves are typically separated from their dam within an h of birth and bottle fed until weaning. Over one-half of dairy calves born in the United States are separated from their dam at birth, 68% during the first 12 hours (Heinrichs et al., 1994), which may also be a means to help prevent the spread of disease, but this requires intensive calf care. Approximately half of dairy calves have the potential to become replacement heifers for the herd. Replacement heifers are one of the largest expensees incurred by the dairies. Some dairies raise their own replacement heifers to help alleviate this cost. However, the cost of producing replacement heifers can still account for 20% of a dairy's expenses as reported by Heinrichs, (1993), second only to feeding costs. Of this cost, 60% is attributed to the cost of feed used to raise these replacement heifers (Gabler et al., 2000). In order for this process to be effective, proper nutrition from birth is essential to ensure the calves remain healthy and mature in the desired amount of time to become part of the herd. Initially, nutrition during the pre-ruminant period is critical and can have long lasting effects. The plane of nutrition during the first 13 weeks can significantly impact body weight, body structure, and carcass composition for at least the first year (Wardrop, 1966). Altering the plane of nutrition in neonatal calves could potentially improve body composition, rumen development, and decrease weaning age.

Rumen Development

Most of the stress at weaning likely results because of the body shifting from glucose as the primary energy source to short-chain fatty acids, or VFAs, as the primary source. At birth, a neonatal calf functions as a monogastric until the rumen develops and the rumen microbial population becomes active in the production of VFAs. Rumen development is associated with the absorption of VFAs. Davis and Clark (1981) identified three phases of development of the rumen: liquid feeding phase, transition phase, and ruminant phase. While milk is high in nutrients, it is digested in the abomasum, bypassing the rumen. Because the rumen is not utilized, it is not given the opportunity to develop until starter feeds are eaten and a rumen bacterial population evolves. Previously, it was believed that forage was necessary for rumen development solely because of the physical texture it provides, creating friction on the ruminal wall. This scratch like effect was thought to stimulate papillae growth. However, when foreign objects, such as plastic bristles and sponges, were placed in the rumen to simulate forage, they failed to stimulate papillae and rumen development indicating the scratch factor was not the impetus for rumen development. Development of the papillae was not observed and epithelia were comparable to that from a milk only diet (Warner et al., 1956). Papillae require both physical stimulation as well as microbial fermentation to fully develop. Calf starter concentrate is composed of easily fermented carbohydrates which are meant to promote rumen function. This easily fermented feedstuff helps the epithelia of the forestomach adapt to diets later in the calf's life (Kristensen, 2007). Both calf starter and forage are necessary for the development of papillae found in the rumen, as well as increase muscle and volume of the rumen. Inclusion of forage may lead to heavier calves with better feed efficiency. Calves provided 7.5% hay in their diet with coarse starter had greater ADG and feed efficiency than calves provided starter with 15% hay or coarse starter alone (Coverdale et al., 2004). These observations may reflect the functioning of the rumen. Decreasing milk allowance and increasing concentrates results in increased concentrations of VFAs and ketone bodies, indicating rumen function.

It has been consistently found that neonatal calves raised strictly on milk diets do not have properly functioning rumens. Reducing milk consumption 30% or 60% increased forage consumption of calves (Broesder et al., 1990). After 87 days of age, total VFA concentration was indiscernible among calves with constant milk replacer compared to those receiving reduced amounts. Papillae of young ruminants are underdeveloped and lack the ability to absorb VFAs. An active and functioning rumen has been observed as early as 3 wk (Kehoe et al., 2007). Most of the development of the rumen occurs from 4 to 6 wk of age in neonates (Warner et al. 1956). Wagner et al. found that calves maintained on a milk only diet did not show an increase in volume of the rumen or omasum. Calves maintained on a milk only diet were observed to have relatively smooth epithelium with papillae less than 2mm even as they reached 16 wk of age. However, calves provided with hay and grain showed papillae reaching 1cm at the same age (Wagner et al., 1956). Papillae are critical to rumen development and function because properly functioning papillae are necessary for absorption of VFAs. Fermentation and production of VFAs are necessary for epithelial development. It is the production of VFAs which leads to proper rumen function because of chemical interactions which occur to promote rumen development and not merely the rough surface of hay or grain provides.

Rumen function may begin at 3 wk, thus it is possible to change calves to a strictly concentrate diet earlier than the traditionally weaning age of approximately 8 wk. A study conducted by Kehoe et al. published in 2007, demonstrated it is possible to wean dairy calves as early as 3 weeks and reach growth comparable to calves weaned at 8 weeks of age. However, the early weaned calves required more labor and more attention to consume the calf starter. With intensive management, dairies could potentially successfully wean calves earlier than traditionally done.

General Health

During the first few weeks of a neonate's life, it is susceptible to a variety of diseases. It is within the initial 30 d that a young dairy calf is most likely to scour (McGuirk, 2008). Scours may be caused by fecal-oral transmission, bacteria, viruses, unpasteurized milk (McGuirk, 2008), or when the milk is fed at improper temperatures (Lundborg et al., 2005). Several studies have indicated that incidence of scours may be more related to management of the facilities and calves, rather than elevated levels of milk or water. Historically, calves were not provided additional access to water, other than that found in their milk for fear that it would increase the incidence of scours. Scouring calves do drink more water; however, this is likely due to dehydration resulting from scours, not the cause of scours (Kertz et al., 1984). Maintaining hydration and rehydrating when necessary, are the primary concerns when a calf scours. Producers should also try to maintain caloric intake for the calves (McGuirk, 2008). Other than scours, respiratory diseases are a concern for dairy calf producers. Approximately 15% of dairy calves will suffer from a respiratory disease requiring treatment before they reach weaning (Stanton, 2009). After the initial 30 days, pneumonia increases in prevalence over scours (McGuirk, 2008). Concern continues through to weaning. Pneumonia in particular may reduce total gain by as much as 0.8 kg for each week it affects a calf under three months of age (Virtala et al., 1996). Pneumonia is best treated with early detection though since infected calves do not display signs typically associated with illness: loss of appetite, dullness, or cough (McGuirk, 2008). Nasal discharge and drooping ears may be used as indicators though testing is needed for confirmation. There are three types of pneumonia found among neonatal calves: aspiration, bacterial, and viral. Aspiration pneumonia is associated with inhalation of solids which may occur when tube-feeding calves (Poulsen and McGuirk, 2009). Treatment varies depending on type of pneumonia and may potentially be treated with antibiotics (McGuirk, 2008). However, observation and prevention decrease the occurrence of outbreaks in the herd.

Colostrum

There are several different methods for feeding calves, each with its own benefits and drawbacks. However, all should commence with adequate levels of colostrum. Traditionally, colostrum is feed at a rate of 2 to 4 liters of colostrum during the first 24 h following parturition. Recently, research shows at least 4 liters needs to be fed in the earliest hours possible after birth.

Colostrum, also known as first milk, is produced by the dam and available within the first hours postpartum. Colostrum differs from milk produced later primarily in the concentrations of antimicrobials, hormones, and growth factors present. Like later production of milk, it contains proteins, carbohydrates, vitamins, and fats necessary for the healthy development of the neonatal calf. During the first few days of its life, a neonatal calf is most susceptible to respiratory and gastrointestinal infections. Calves are susceptible to disease due to their lack of a developed an immune system at birth. Their immune system is developed by antimicrobials and hormones acquired through passive immunity, particularly from colostrum. There has been some discussion as to how long the benefits of colostrum are available to the neonate calf; how long is the calf able to utilize colostrum to the full potential. Traditionally, it is believed colostrum is only beneficial for the first 24 hours. In a study conducted by Hammon et al. in 2002, varying amounts of colostrum were feed to determine how long calves were able to absorb nutrients available from colostrum. Calves allowed unlimited amounts of colostrum for 3 days, which then received milk until 28 days of age were compared to calves receiving recommended amounts of colostrum and milk. Results showed an increase in feed consumption of milk. Calves allowed ad libitum colostrum and milk had higher levels of insulin yet lower levels of IGF-1. There was no difference observed in glucagon levels or urea concentrations (Hammon et al., 1998). Increases in glucagon and urea concentrations have potential to result in increased growth and increased levels of muscle cell production. The calves receiving free access to colostrum and milk consumed more feed yet had lower levels of feed efficiency compared to their counterparts. It is only within the first 24 to 36 hours that the calf is able to completely utilize and benefit from all of the nutrients available in colostrum. If colostrum is withheld for 24 hours, then later provided, the calf is unable to absorb the immunoglobins from the colostrum due to decreased absorption capabilities (McCoy et al., 1969). The immunity passed from the dam to the newborn calf is primarily the result of adequate ingestion of the antimicrobial factors present in the dam's milk.

Dairies utilize three types of colostrum: natural, pooled, and synthetic. Natural colostrum is colostrum produced directly from the dam, pooled colostrum is obtained from multiple dams and stored for subsequent use. Problems associated with pooled colostrum include the dilution of nutrients and the potential spread of disease if milk from an infected dam is included. The natural colostrum or pooled colostrum provides the immune system of a calf more passive immunity than synthetic colostrum. Synthetic colostrum is more expensive, though it is useful if no other colostrum is available. The type of colostrum used by the dairy depends primarily on the management and collection of colostrum.

Regardless of the source, colostrum includes several components which strengthen the calf's immunity. The antimicrobial compounds of colostrums help resist these infections. One such component is lysozyme. Lysozyme is present in both milk and colostrums, though concentration in colostrums tends to be higher than found in milk, 0.14 to 0.70 mg/L compared to 0.07 to 0.60 mg/L (Pakkanen and Aalto, 1997). This enzyme is known to disrupt the membrane of Gram-negative bacteria, such as *E. coli*. The concentration of this specific strand of lysozyme helps protect neonatal calves from certain infections. Lactoperoxidase is another antimicrobial typically found in colostrum and milk. The epithelial cells in the bovine mammary gland secretes lactoperoxidase which helps prevent infection caused by Gram positive and Gram negative bacteria (Pakkanen and Aalto, 1997). In particular, it affects *Streptococcus, Staphylococcus,* and *Listeria* and reduces infections caused by these pathogens. Lactoperoxidase works by producing a toxic oxidation product, thus prohibiting bacterial metabolism (Pakkanen and Aalto, 1997). Another antimicrobial commonly found in colostrum and milk is the glycoprotein lactoferrin. It leads to an increase in iron bound by the intestines, and the activity of phagocytes. Like lactoperoxidase and lysozyme, it inhibits growth of some bacteria by binding to iron. Antimicrobials are not the only component in colostrum increasing the immunity of neonatal calves. Immunoglobins help decrease the occurrence of respiratory disease in young calves. The most common immunoglobin in colostrum is IgG. IgG actually begins pooling into the colostrum a few weeks prepartum (Parakanin and Aalto, 1997) leading to increased levels compared to other immunoglobins. It is recommended that immunoglobin levels are at least 20 g/L. After the first 24 hours postpartum, concentrations in milk were only half of the initial concentrations measured in the colostrum. Within 7 days, levels stabilized to "about 14% of its initial value" (Aranda et al. 1991).

Development of the immune system is not the only benefit of colostrum. It also plays a key role in the development of the gastrointestinal system of the neonate. While colostrum is necessary for proper development of the gastrointestinal tract and immune system of neonatal calf, the window of opportunity is limited. Once this time frame expires, the body is unable to capitalize on colostrum. Colostrum has been linked to increased development of villi in the small intestine (Blattler et al. 2001). Colostrum-fed neonates were found to have villi with greater area resulting in increased levels of absorption. Feeding colostrum also increases other aspects of digestion, including anabolic metabolism (Hammon et al. 1998). By unlocking more substrates, increased levels of gluconeogensis and protein synthesis are able to take place, promoting growth in young calves. The benefits of colostrum should not be overlooked and are critical for the health of the calf.

Milk and Milk Replacer

Producers should provide quality milk or milk replacer to their calves as this is the initial source of nourishment for the neonatal calf. Unlike beef calves which are typically allowed to suckle their dam, often several times a day, dairy calves are provided pooled milk or milk replacer distributed through buckets or bottles usually twice per day. Calves allowed to suckle had greater ADG and BW compared to calves fed in a bucket. At weaning, this advantage was no longer apparent and bucket-fed calves had a greater ADG and BW. Most likely this difference is due to stress associated with weaning which the bucket-fed calves were able to better endure (Bar-Peled et al., 1997).

Milk replacer provides similar nutrition as whole milk but has a few drawbacks. It may have heat damaged proteins which are not readily digested (Erberdobler and Gropp, 1973). Compared to whole milk, milk replacer had 22.5% fewer total amino acids (Lynch et al., 1978). Phenylalanine and tryptophan may potentially be limiting growth in conventionally fed calves (Terre et al., 2006). Some milk replacers have also been found to pass the abomasum as a watery clot which cannot be properly digested (Johnson and Leibholz, 1976). However, it is still a nutritional alternative to whole milk and capable of supporting comparable growth. Feeding milk replacer may cause concerns about nutrient availability; however, the nutrient content of whole cow milk may be unknown. Many dairy producers feed unmarketable milk containing antibiotics to their calves and do not know the nutrient content of the milk, the antibiotic levels in the milk, or the exact amount fed to calves daily. Records of this information would help producers improve efficiency of the operation.

Traditionally, dairy calves are provided with milk at 1.0% of body weight on a DM basis daily, in two feedings. It has been argued this is below the calf's potential for consumption. Restricting milk intake generally results in low nutrient availability (Egli and Blum, 1998; Appleby et al., 2001), poor health (Huber et al., 1984) and reduced productivity of dairy calves (Pollack et al., 1993). Increased milk powder consumption and total increase of milk powder protein and milk powder fat produced calves which were heavier and performed better post-weaning (Berger et al., 2008). Jasper and Weary (2002) found calves allowed ad libitum consumption of milk consumed significantly more milk compared to those fed conventional amounts. The amount of milk consumed averaged 8.8 kg/d; this level was maintained until weaning. They reported calves fed ad libitum consumed 89% more milk and weighed 63% more than those fed conventional amounts (Jasper and Weary, 2002). Richard et al. (1988) had also observed that calves fed ad libitium milk replacer consumed more than those provided with milk replacer twice daily. Increased levels of milk replacer resulted in decreased calf starter consumption (Jasper and Weary, 2002; Richard et al., 1988). Though they consumed less starter and hay prior to weaning, there was no difference in the amount of solid food consumed compared to those fed conventional amounts during the post-weaning phase (Jasper and Weary, 2002). Regardless if calves are provided ad libitum access to milk, they should be allowed ad libitum access to water. Calves provided only milk had lower weight gain and starter intake than calves which had ad libitum access to water. Ad libitium access to water promoted starter consumption and resulted in heavier weights (Kertz et al., 1984). Providing neonatal calves with increased levels of nutrients has been associated with greater ADG along with heavier weaning weights. While they did not consume great amounts of feed prior to weaning, solid feed intake increased to comparable levels of conventionally fed calves post-weaning while maintaining their weight advantage. Hammon et al. (2002) found reduced blood cortisol levels in calves fed ad libitium, indicating lower stress levels.

While ad libitum milk consumption does not demonstrate detrimental effects, other factors must be considered. Though calves are able to consume more than what is conventionally given, increased milk feeding is associated with decreased consumption of starter and forage, greater stress at weaning, underdeveloped rumens, and higher costs associated with the price of milk replacer and labor. However, reduced starter feed and forage consumption is associated with suppressed growth during post-weaning performance due to delayed ruminal development in the neonatal calf (Baldwin et al., 2004).

Several studies have compared varying levels of milk replacer concentrations to determine the effect on starter and forage intake and growth and development. Pettyjohn et al. (1963) concluded that milk replacer fed at a concentration of 15% DM resulted in better gain and efficiencies compared to concentrations of 5, 10, 20, and 25% DM milk replacer. Calves were unable to benefit from the higher levels of DM, 20 and 25%, which possibly indicated physical inability to utilize all the provided nutrients (Pettyjohn et al., 1963). At lower DM levels, 5 and 10%, consumption increased, indicating an attempt to compensate for the lack of nutrients (Pettyjohn et al., 1963). Nutrient value must also be considered when determining the amount fed since CP may be a limiting growth factor. Neonatal dairy calves require more than 0.45 kg/d of milk replacer with more than 20% CP in order to demonstrate improved weight gain (Hill et al., 2006). Brown et al. (2005) found that heifer calves fed high levels of protein and energy from 2 to 8 weeks of age had more body fat than calves fed lower amounts; however the mass of mammary parenchyma was nearly three times that of those fed lower amounts, indicating more milk production potential when mature. However, increasing protein and energy at 8 to 14 weeks increases fat deposition in the udder, possibly reducing the milk production capacity of the heifers when mature.

In effort to increase nutrient availability while promoting rumen development, combinations of restricted and ad libitium milk feeding strategies have been evaluated. Recently accelerated growth programs have been promoted by many dairy calf nutrition companies in an effort to wean heavier calves at an earlier age. Heifers are fed for accelerated growth in an effort to decrease the age at first calving in effort to allow them to enter the herd sooner and alleviate some of the cost of raising replacement heifers and maintaining calves. However, decreasing weaning age would increase labor requirements. Accelerated feeding strategies provide calves with higher amounts of milk and often provide access to grain and forage. These higher levels of milk are maintained throughout the preweaning period. Barlett (2006) found that calves offered milk replacer at 1.75% body weight had increased ADG and improved gain to feed ratio while decreasing the percent of the protein and nitrogen in plasma when compared to calves offered milk replacer at 1.25% body weight. They did not see a significant difference in fecal scores between these treatments. Results show that calves given more milk had more energy available to be used for growth. However, adequate utilization of amino acids by accelerated fed calves is only possible if enough energy is provided (Terre et al., 2006). When given differing amounts of milk replacer powder (0.63 kg/d compared to 1.15 kg/d), calves receiving higher quantities demonstrated greater body weight, ADG, feed intake, and feed efficiency. When the visceral organs were examined, calves receiving the higher milk quantities had heavier spleen, liver, kidney, and internal fat absolute weights than their counterparts. However, the head and large intestine weights were lower (Kamiya et al., 2009). These findings indicate that increased nutrition provided by high levels of milk promoted the development of internal organs, potentially leading to increased productivity and immunity (Kamiya et al., 2009). Another study provided calves with milk replacer at three different amounts: maintenance level, 1.5 times maintenance, and 2.0 times maintenance level. They did not report any differences in starter intake during the time period of 70 days. The greatest difference in weight gain was during the initial 28 days which corresponds with the time period when calves consume limited amounts of starter (Fallon and Harte, 1986). When comparing calves fed 1.09 kg of DM/d with calves feed 0.66 or 0.44 kg/d in milk replacer, calves receiving 0.66 kg/d had BW comparable to calves receiving 1.09 kg and had higher BW compared to calves receiving lower levels. These calves also had weights comparable to calves receiving 1.09 kg, yet calves receiving 0.66 kg/d were consuming more calf starter (Hill et al., 2010).

A feeding strategy known as the step-down method provides a balance between conventional and accelerated feeding strategies. A step-down method described by Khan et al. (2007) provided milk at a rate of 2.0% body weight compared to 1.0% as is traditionally given. After day 25, the milk provided is reduced to 1.0% DM by diluting the milk with water (Khan et al., 2007). It was observed that calves fed with the step-down method consumed more milk. Though solid feed consumption is lower at the beginning, there is an increase in starter and hay consumption once the reduction in milk occurs. This is likely due to higher caloric requirements resulting from greater body weight and organ size compared to conventionally fed calves (Khan et al., 2007). Calves fed through the step-down method demonstrated greater papillae concentration, as well as papillae length and width, and forestomach mass than calves fed using conventional methods.

During this period of life of the neonatal calf, it is essential to provide adequate nutritional requirements to promote weight gain and rumen development. More research must be conducted to determine the optimal combination of milk and starter to produce quality replacement heifers more efficiently. Producers determine the feeding strategy to be used based upon their knowledge and available resources. Influence of the environment should not be overlooked when managing neonatal calves. However, limited information is available in regards to how the different feeding strategies are influenced by heat stress.

CHAPTER III

ADJUSTING MILK REPLACER INTAKE DURING HEAT STRESS AND NON-HEAT STRESS AS A MEANS OF IMPROVING DAIRY CALF PERFORMANCE

Introduction

The stress created in elevated ambient temperatures and humidity leads to physiological responses by the animal and a reduction in productivity. Decreased DMI, lowered rate of gain, and reduced feed efficiency are some results of exposure to heat stress in dairy cows. Calves may show similar responses to heat stress, though the effect of elevated THI values on their growth is not extensively documented

Dairy calves are typically given a restricted, amount of milk, ~1.0% of BW daily. Restricting milk intake generally results in low nutrient availability (Egli and Blum, 1998; Appleby et al. 2001), poor health (Huber et al., 1984) and reduced productivity of dairy calves (Pollack et al. 1993). Recently, enhanced feeding programs have been promoted in effort to wean heavier calves at an earlier age and decrease age at first calving. This could possibly alleviate some of the cost of raising replacement heifers which accounts for approximately 20% of dairy farm expenses (Heinrichs, 1993). Jasper and Weary (2002) found that when calves were allowed ad libitum consumption of milk, they consumed almost double compared to those fed conventional amounts. Ad libitum fed calves remained healthier as well. However, ad libitum consumption of milk can lead to decreased consumption of starter. Reduced starter feed consumption is associated with poor post-weaning performance due to delayed ruminal development

(Baldwin et al. 2004). Modifying diets of neonatal calves may lead to improved health while reducing cost of development. The objective of this study is to determine the effects of heat stress and milk replacer levels on dairy calf performance.

Materials and Methods

Holstein bull calves served as a model for this study. Sixty calves were used to initiate the study, with all animals managed similarly. All care and sampling was approved by the Institutional Animal Care and Use Committee of Texas A&M University (AUP #2009-106).

Calves were obtained from two dairies in the Texas Panhandle at 1 to 2 d of age with an average weight of 41 kg. All calves received colostrum at the dairy of origin. They were transported 9.5 h overnight in a covered trailer to Texas A&M University's Nutrition and Physiology Center, College Station, Texas. Upon arrival, calves were given 2 L of milk replacer. Calves were then weighed, ear-tagged, and received metaphalaxis treatment of 1 cc Draxxin® (Pfizer Animal Health, Exton, PA). Blood samples were obtained to evaluate total serum protein levels.

Calves were assigned treatment groups randomly based on initial body weight, visual health score, and total serum protein level including those with failure of passive immunity (< 5.5). Treatments were arranged as a 3 × 2 factorial with three levels of milk replacer and two housing groups. These housing groups were selected to subject the calves to differing levels and durations of heat stress. Twenty-nine calves were housed inside a controlled environment with 24 h lighting and an average temperature of

23.0ºC, with daily average high of 25.5ºC and average low of 21.3ºC for the duration of the trial which was considered non-heat stress (NHS). Each calf was assigned an individual pen 1.85 m^2 with slated floors. Twenty-eight calves were housed outside in individual pens, constructed with 1.22 m cattle panels on concrete flooring, in an open air, shaded barn with an average temperature of 30.0ºC, average daily high of 37.4ºC and average low of 25.1ºC for the duration of the trial, conditions considered heat stress (HS). Temperature-humidity index (THI) was calculated using ambient temperature and relative humidity from data loggers (H08-003-02 HOBO® devices, Onset Computer Corporation, Pocasset, MA, USA) mounted in the shade near the calves. The THI equation used in this study was THI = ambient temperature – [0.55 - (0.55 * relative humidity/100)] * (ambient temperature – 58.8), where ambient temperature was recorded in Fahrenheit and relative humidity was recorded as a percentage (NOAA, 1976). Calculated THI values were categorized into differing levels of heat stress: < 72, no stress; 72 to 79, mild; 80 to 89, moderate; 90 to 99, severe. All calves had access to rubber mats which covered half of their pens for comfort. Pens were washed daily.

All calves were assigned to one of three milk replacer feeding treatments of 20% CP, 20% Crude Fat Land O' Lakes (Land O'Lakes, Inc., Arden Hills, MN) milk replacer powder: increasing (INC), decreasing (DEC), or constant (CON). The INC treatment increased milk replacer powder from 1.1% BW by 0.1% weekly until 1.5% BW was reached. The DEC treatment decreased the amount of milk replacer powder from 1.6% BW to 1.2% BW by 0.1% weekly. The CON treatment group received 1.1% BW in milk replacer powder throughout the study. Initially, during a one week adaptation period, all calves were given 1.1% BW, DM basis, in milk replacer. Differences in milk replacer level began on d 9 of the study with calves receiving assigned milk replacer levels on DM basis, based upon individual weight obtained biweekly for the remainder of the trial. It was determined that calves would receive a maximum of 1,000 g/d or 500g/feeding of milk replacer powder due to the resulting osmolality being too great and this would cause dehydration problems for the calves. Milk replacer powder was individually weighed for two feedings at 0600 and 1800 h. It was then mixed with warm water (approximately 39.4ºC) using an electric handheld mixer. Bottles were equipped with nipples and secured in bottle holders during the feedings. Prior to feedings, rectal temperatures were obtained using digital thermometers. Fecal scores were also recorded at this time on a scale of 1 to 4: 1 = firm, formed, 2 =soft formed, 3 = soft unformed, and 4 = watery. Calves with a fecal score of 3 or 4 were observed more closely and received oral electrolytes if needed to maintain hydration. After feedings, respiration rates were recorded. These were obtained through direct observation of the costal region as the calf was at rest for duration of 15 seconds. This number was then multiplied by 4 to be expressed as breaths per minute. Respiration rates and body temperatures were used to help monitor health of the calves. A commercially available calf starter of 18% protein and 3% fat (Calf Choice 18% DX, Producers Cooperative Association, Bryan, TX) and water were provided ad libitum. Daily intake of water (ml) and starter feed (g) were recorded daily at 1800 h. Body weight, wither height, and heart girth circumference were collected biweekly and milk replacer powder amounts were adjusted after each body weight measurement. Once a week, all calves were allowed 1 hr of exercise in a partially covered outdoor pen; HS and NHS did not interact. Calves were weaned at 40 days of age. Three calves (one NHS × CON, one HS × INC, and one HS × DEC) were excluded from analysis due to death (n = 1) or health concerns (n=2). Day 30 was excluded for fecal score analysis due to missing observations.

All statistical analyses were carried out using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Main effects were milk replacer level, housing, day, milk replacer level × housing, and milk replacer level × housing × day. Factors evaluated included: ADG, starter intake, water intake, AM rectal temperatures, PM rectal temperatures, AM respiration rates, PM respiration rates, and fecal score. Interactions among housing, milk replacer levels, and day were also evaluated. P-values less than 0.05 were considered statistically significant while values between P > 0.05 and P < 0.10 were considered a trend.

Results and Discussion

Interactions

Interactions between housing, milk replacer levels, and day, housing × milk replacer level × day, were found to be not significant for any of the responses measured (P > 0.05): ADG, feed, water, rectal temperature (AM & PM), respiration rate (AM & PM), fecal score, and treatment for scours, fever, or respiratory disease. Two way interactions for housing and milk replacer level, housing × milk replacer level, and for milk replacer level and day, milk replacer level × day, were not found to be significant (P > 0.05). However, housing and day interactions, housing × day, were significant for water, rectal temperatures (AM & PM), respiration rates (AM & PM), and fecal score ($P < 0.01$), though not significant for feed ($P > 0.05$) (Table 1).

Table 1. Interaction between housing and milk replacer levels.

	Treatment							
	Non-heat Stress[1]			Heat Stress				
Response	**INC[2]**	**CON**	**DEC**	**INC**	**CON**	**DEC**	**SE**	**P-value**
ADG	0.77	0.78	0.82	0.63	0.64	0.66	0.05	0.98
Feed	1.73	1.97	1.63	1.14	1.31	1.05	0.10	0.90
Water	2153	1729	3131	4085	3498	4184	177	0.05
TempAM	38.68	38.71	38.81	38.62	38.54	38.69	0.05	0.14
TempPM	38.79	38.8	38.81	38.97	38.84	38.97	0.05	0.05
RRAM	33.05	32.96	35.31	34.22	35.32	36.58	0.70	0.67
RRPM	33.85	34.28	37.56	43.69	45.72	47.60	1.20	0.79
Fecal	1.36	1.29	1.38	1.15	1.14	1.20	0.03	0.67
Scours	0.10	0.11	0.20	0.78	0.50	1.00	0.40	0.86
Banamine	1.10	0.67	0.90	0.89	0.80	1.89	0.50	0.45
Draxxin	1.40	0.67	0.70	1.11	0.90	1.22	0.30	0.50

[1] Housing treatment groups. HS= Heat Stress and NHS= Non-heat stress housing environments
[2] Milk replacer treatment groups. CON= Constant milk replacer level (1.1% BW in milk replacer); INC= Increasing milk replacer level (1.2% BW in milk replacer to 1.5% adjusted weekly); DEC= Decreasing milk replacer level (1.5% BW in milk replacer to 1.2% adjusted weekly).

Housing

Though there was no interaction between milk replacer levels and housing, there were differences found between the housing groups (Table 2). Response measurements were evaluated to determine differences in performance and health. Values for THI differed for HS and NHS. For HS calves, THI values ranged from 72 to 85 with 53% of these values being classified as mild heat stress and 47% classified as moderate heat stress. For NHS calves, THI values ranged from 62 to 79 with 57% of these observations classified as no stress and 43% classified as mild stress. Average hourly values revealed a peak in THI between the hours of 15:00 and 17:00 (Figure 3). This appears to have influenced ADG because values were greater for NHS calves (0.79 ± 0.03 kg/d) compared to HS calves (0.64 ± 0.03 kg/d), resulting in differing body weight (Figure 4).

Table 2. Responses to housing environment.

	Housing[1]			
Response	**NHS**	**HS**	**SE**	**P-Value**
ADG	0.79	0.66	0.03	< 0.01
Feed	1.77	1.16	0.06	< 0.01
Water	2338	3923	105	< 0.01
TempAM	38.73	38.62	0.02	< 0.01
TempPM	38.80	39.28	0.01	< 0.01
RRAM	33.77	35.37	0.42	0.01
RRPM	35.23	45.67	0.70	< 0.01
Fecal	1.34	1.16	0.02	< 0.01
Scours	0.14	0.76	0.22	0.05
Banamine	0.89	1.19	0.28	0.45
Draxxin	0.92	1.08	0.20	0.58

[1] Housing treatment groups. NHS= Non-heat stress and HS= Heat stress housing environments

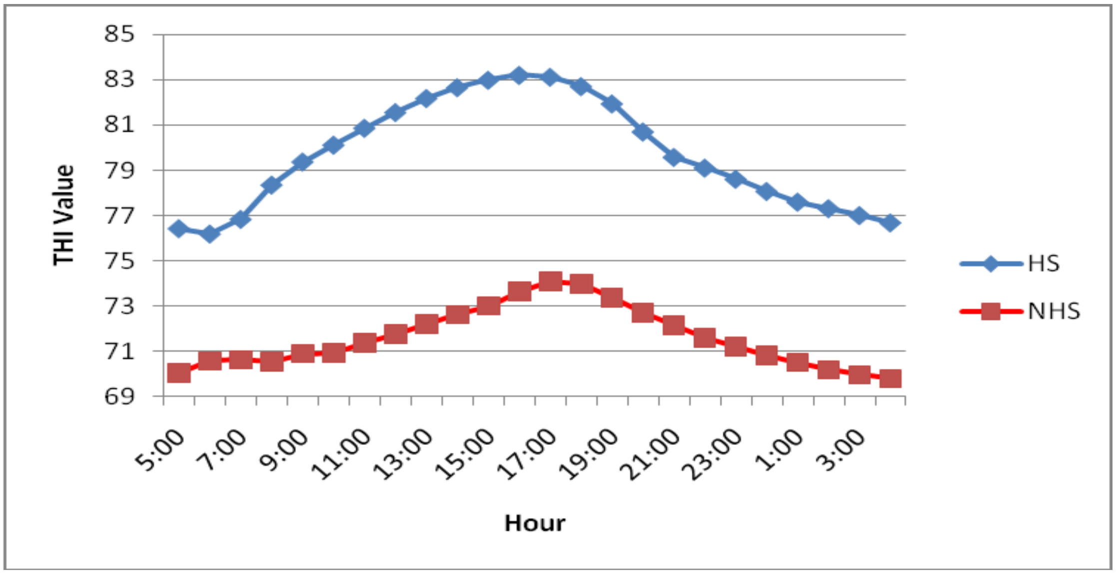


Figure 3. Average hourly THI values from d 2 to d 40 of trial for both housing groups.

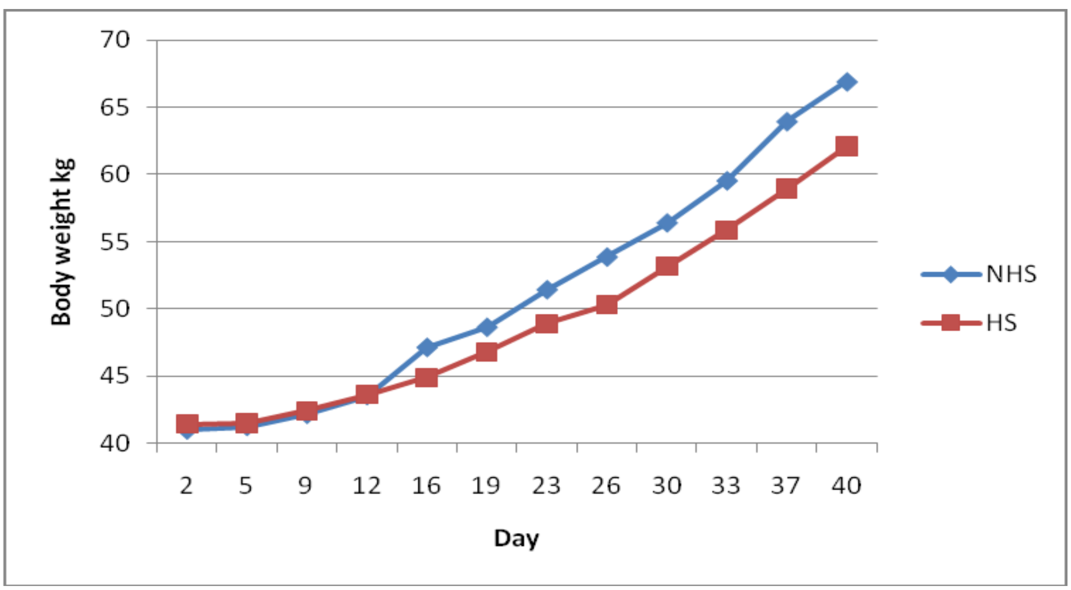


Figure 4. Mean weights for HS and NHS calves.

Calves subjected to thermal stress gained less; the ability to consume and absorb nutrients is limited when in heat stress situations (Beede and Collier, 1986). This difference in weight gain may be partially contributed to the difference in starter intake between the two housing groups (Figure 5). The NHS calves consumed more starter (P < 0.01) than HS (1.78 ± 0.06 vs 1.17 ± 0.06 kg/d). This may be partially due to increased heat production which leads to decreased feed intake (Brown-Brandl et al., 2003). Studies have shown that as ambient temperatures increase, so does water intake, particularly above 27°C (Beede and Collier, 1986). The HS calves consumed more (3923 ± 106 mL/d) water than NHS (2338 ± 104 mL/d) (P < 0.01) (Figure 6).

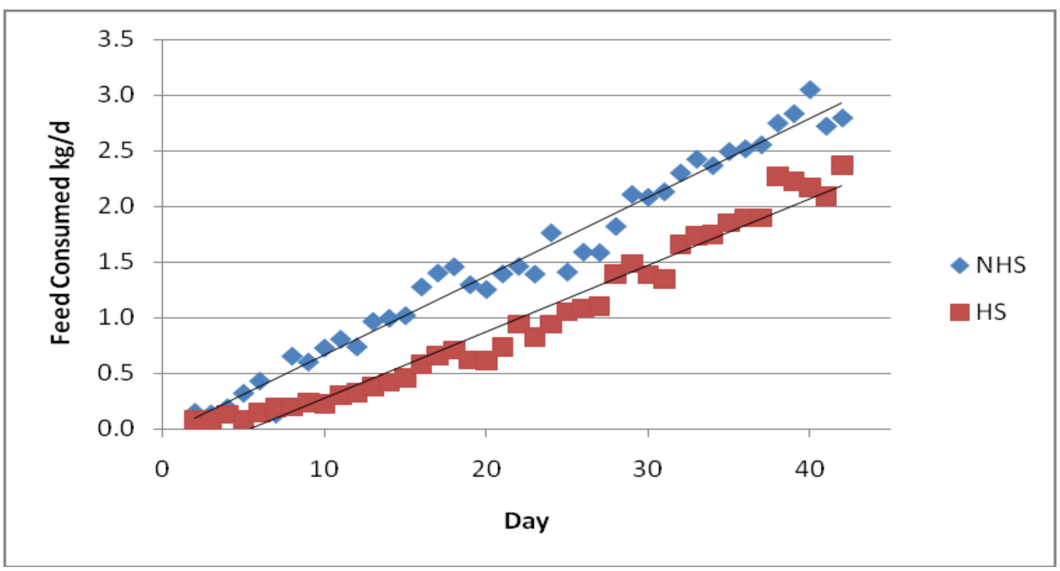


Figure 5. Mean feed consumption for HS and NHS housed calves beginning on d 2 of trial.

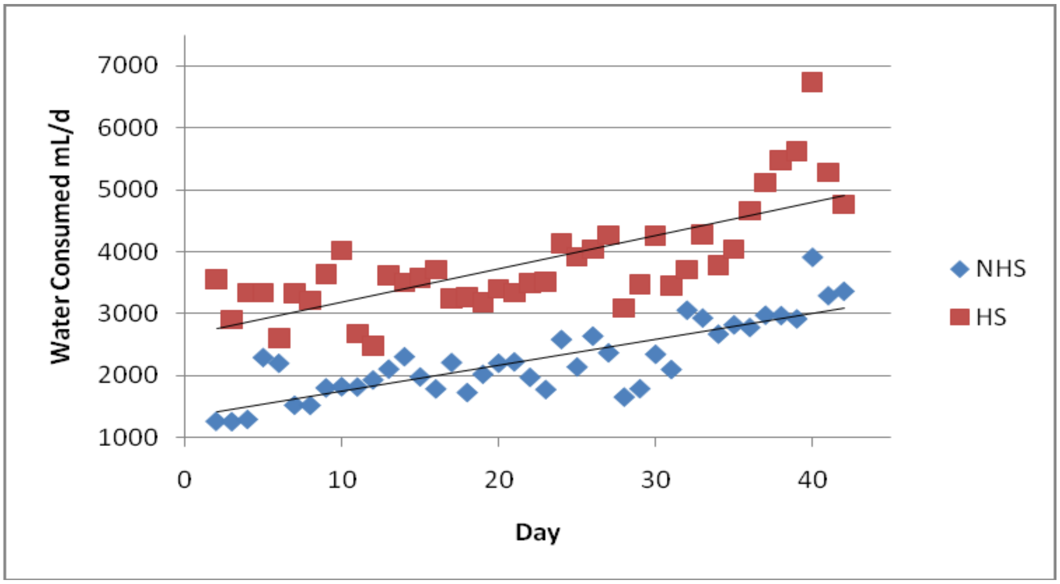


Figure 6. Mean water consumption of HS and NHS calves beginning on d 2 of trial.

Calves also exhibited physiological responses to heat stress. Rectal temperature is one of the best methods to determine thermal stress in animals. During PM hours, HS calves exhibited higher rectal temperatures ($P < 0.01$) than NHS calves (38.93 ± 0.01 vs 38.80 ± 0.01). However, NHS calves had greater rectal temperatures in the AM than did HS (38.73 ± 0.02 vs 38.62 ± 0.02; $P < 0.01$). The difference in rectal temperatures between AM and PM may reflect the ability of the calves to dissipate heat during nightime hours. Calves housed outdoors likely were able to dissipate heat accumulated throughout the day while calves housed indoors were unable to dissipate as much heat due to their artificial environment: lack of diurnal variation, solar radiation, and air currents (Albright and Alliston, 1971). When rectal temperatures were recorded over a 24 hour period, the lowest values were recorded between 0430 and 0500, when ambient temperature was at its lowest (Berman, 1968; Holub, unpublished). Ambient temperature was lower outdoors during the early morning hours, exposing HS calves to a cooler environment. This difference from the daylight hours appears to be sufficient to allow calves to dissipate greater amounts of heat to lower their body temperatures, reflected in rectal temperatures. Lemerle and Goddard (1986) stated that rectal temperatures increased when THI was above 80; Magdub et al. (1981), also reported higher rectal temperatures during heat stress.

A similar observation was not found in respiration rates. Respiration rates also increase as body temperatures increase in an effort for the calf to cool its body. The HS calves had significantly higher respiration rates both in the AM (35.37 ± 0.42 vs 33.77 ± 0.42 breaths/min) and PM (45.67 ± 0.70 vs 35.23 ± 0.70 breaths/min; $P < 0.01$) than did NHS, with a greater difference between the two groups observed in the PM hours (Figures 7 and 8). Respiration assists in evaporative cooling for the animal; rates begin increasing once THI surpasses 73 (Lemerle and Goddard, 1986). Cooling from increased respiration rates is able to assist in the prevention of rectal temperatures until THI reaches 80 (Lemerle and Goddard, 1986). In cattle, 20 breaths/min is considered basal level. As this rate approaches 40 breaths/min, it is regarded as panting (Silvanikove, 2000). While both housing groups were slightly above basal level during the AM, only HS calves exhibited panting levels during PM hours. When observing individual days, respiration rates during the first two weeks were higher than the remainder of the study. However, there was no distinct difference in THI values.

Lowered respiration rates may indicate that HS calves may have acclimated to their environment over time.

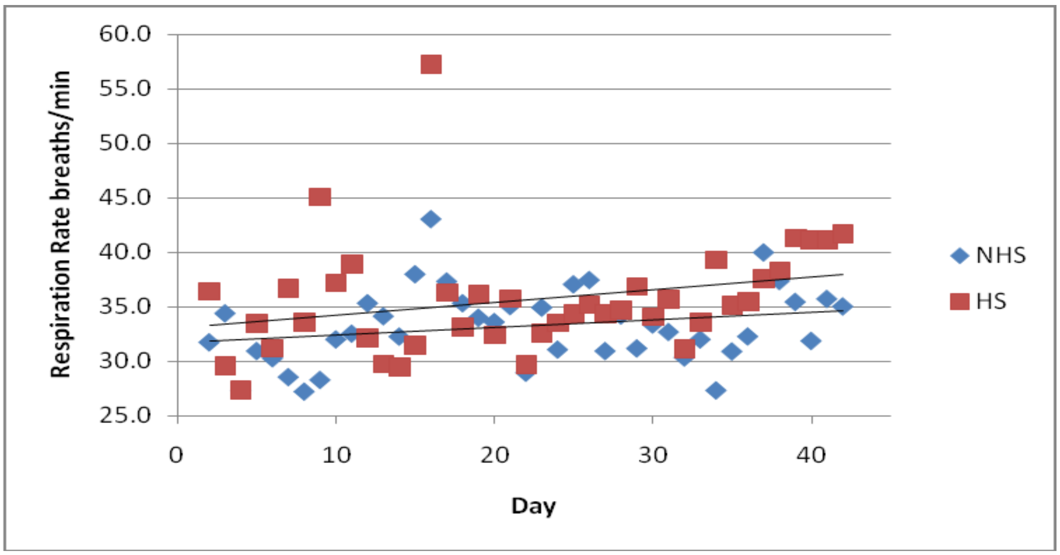


Figure 7. Mean respiration rates for HS and NHS calves during AM observations from d 2 to d 40.

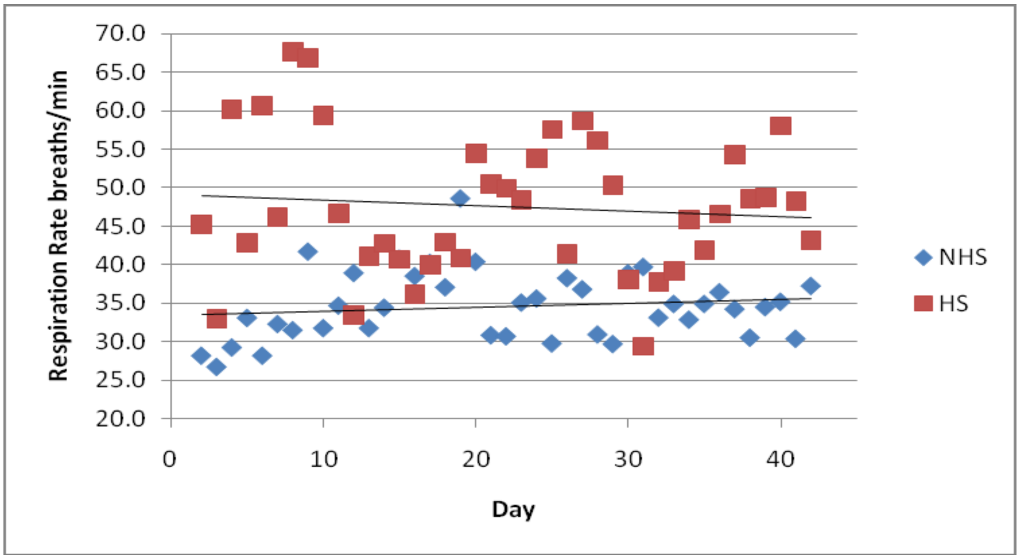


Figure 8. Mean respiration rates for HS and NHS calves during PM observations from d 2 to d 40.

A significant difference was found in fecal score for HS was 1.16 ± 0.02 while NHS was 1.34 ± 0.02 ($P < 0.01$). However, there was no significant difference in health treatments for scours, respiratory disease, or fever ($P > 0.05$).

Milk Replacer Levels

Like housing, differences among milk replacer levels were observed though no interaction between housing and milk replacer levels occurred (Table 3). Though calves were placed on different levels of milk replacer, overall milk replacer amounts were not significantly different between CON and DEC ($P = 0.07$). However, milk replacer amounts were significantly different from d 9 to d 29 and d 37 to d 40 ($P < 0.01$), and though not significantly different from d 30 to d 36 ($P = 0.10$) for these two groups.

Total milk replacer levels for INC were significantly different from both CON and DEC (P < 0.01), d 9 until weaning (Figure 8).

Table 3. Response to milk replacer levels.

	Milk Replacer Levels[1]				
Response*	**INC**	**CON**	**DEC**	**SE**	**P-Value**
ADG	0.70	0.71	0.74	0.04	0.73
Feed	1.44_{a}	1.64_{b}	1.34_{a}	0.07	0.01
Water	3119_{ab}	2614_{a}	3657_{b}	129	< 0.01
TempAM	38.65_{a}	38.62_{a}	38.74_{b}	0.02	< 0.01
TempPM	38.88_{a}	38.82_{b}	38.89_{a}	0.01	0.04
RRAM	33.64_{a}	34.12_{a}	35.94_{b}	0.51	0.01
RRPM	38.77_{a}	40.00_{a}	42.58_{b}	0.89	0.01
Fecal	1.25	1.22	1.29	0.02	0.10
Scours Trt	0.44	0.31	0.60	0.27	0.75
Respiratory Disease Trt	0.99	0.73	1.39	0.35	0.40
Fever Trt	1.26	0.78	0.96	0.24	0.39

[1] Milk replacer treatment groups. CON= Constant milk replacer level (1.1% BW in milk replacer); INC= Increasing milk replacer level (1.2% BW in milk replacer to 1.5% adjusted weekly); DEC= Decreasing milk replacer level (1.5% BW in milk replacer to 1.2% adjusted weekly).
*Within responses, means with different subscript letters are significantly different (P < 0.05)

Unlike housing, no significant differences were found among the milk replacer groups in terms of ADG (P = 0.73). Average daily gain was similar among the three groups; calves which received CON milk replacer gained 0.71 ± 0.04 kg/d; calves on INC treatment gained 0.70 ± 0.04 kg/d; and DEC calves gained 0.74 ± 0.04 kg/d (Figure 9). In a similar study with calves fed different levels of milk replacer and where the initial age was approximately 15 days, those with increased levels of milk had greater ADG for the initial 27 days. However, from d 27 to d 45, conventionally fed calves had a greater ADG; yet after d 45 there was no difference (Terré et al., 2006). Another study where calves were fed two different levels of milk reported no difference in BW for the initial three weeks; thereafter calves with higher milk levels had greater BW (Kamiya et al., 2009).

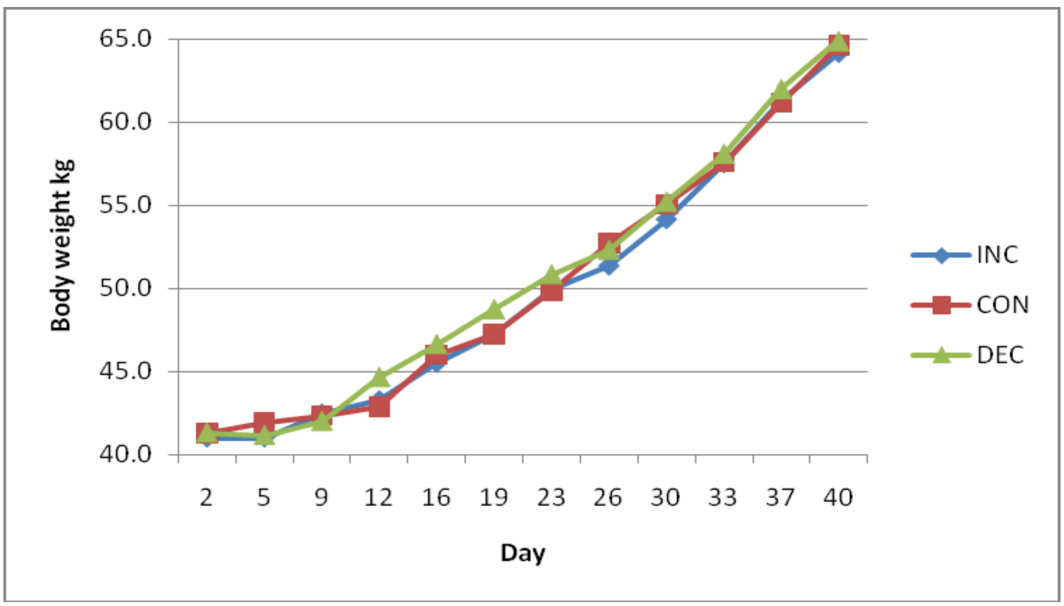


Figure 9. Body weight for milk replacer levels on weigh days.

For this study, milk replacer levels had a significant impact ($P < 0.05$) on the amount of calf starter consumed with CON consuming the most (1.64 ± 0.07 kg/d), followed by INC (1.44 ± 0.07) and DEC consuming the least (1.34 ± 0.07 kg/d) (Figure

10). Amount of feed consumed by CON was significantly different from INC ($P < 0.05$) and DEC ($P < 0.01$), though INC and DEC were not significantly different from each other ($P = 0.60$). Amount of calf starter consumed appears to have a negative correlation with water consumption, which was also significantly impacted by milk replacer levels ($P < 0.01$) (Figure 11). While the DEC calves consumed the least amount of starter, they consumed more water (3657 ± 128 mL/d) than INC calves (3119 ± 128 mL/d), while CON consumed the least amount of water (2613 ± 128 mL/d). These recorded amounts were significantly different between DEC and CON ($P < 0.01$); however INC amounts were not significantly different from either DEC ($P = 0.07$) nor CON ($P = 0.16$) (Figure 9). Water consumption was significantly different between CON and DEC for weeks 1 to 5 (weeks 1 to 4: $P < 0.01$; week 5: $P < 0.05$). From week 1 to 2, INC water consumption was significantly different from DEC ($P < 0.01$) and then became significantly different from CON ($P \leq 0.05$) for weeks 3 to 5. The group which consumed the most feed, CON, consumed the least water which is similar with other studies (Pettyjohn et al., 1964; Lineweaver and Hafez, 1967; Terré et al., 2007).

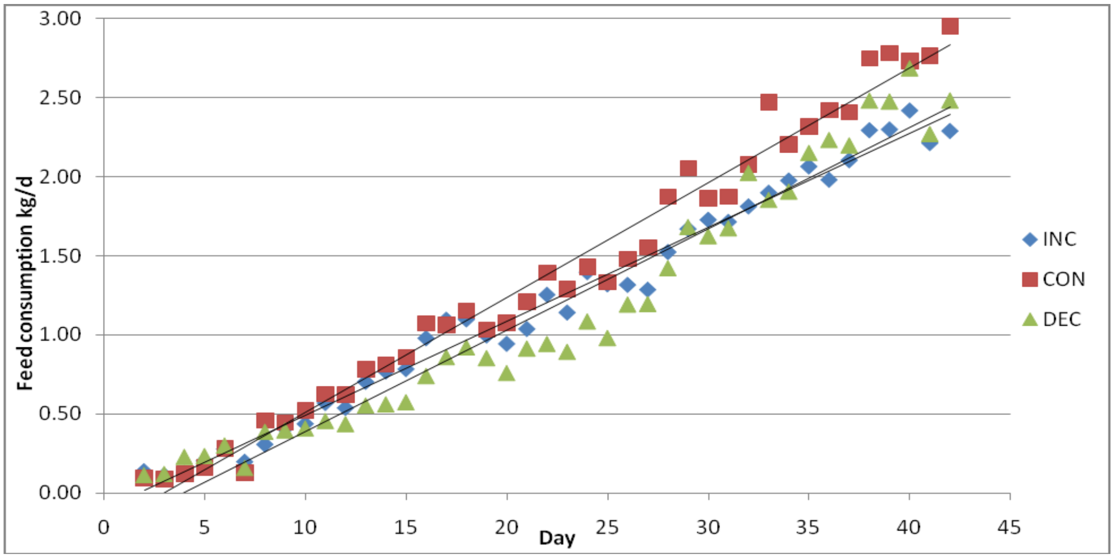


Figure 10. Mean feed consumption for milk replacer levels from d 2 to d 40 of trial.

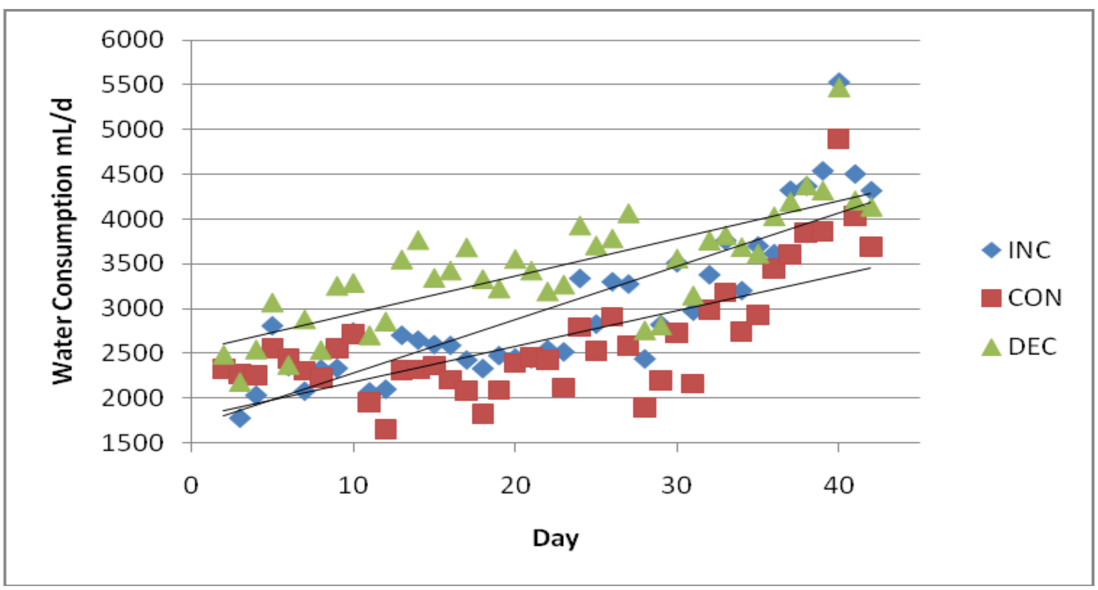


Figure 11. Mean water consumption by milk replacer levels from d 2 to d 40.

Similar to housing, the group with the highest rectal temperatures in the AM was not the same treatment group as the PM. Those on DEC treatment had significantly higher rectal temperatures in the AM compared to INC and CON calves (38.74 ± 0.02, 38.65 ± 0.02, and 38.65 ± 0.02, respectively; $P < 0.01$). Rectal temperatures for INC or CON were not significantly different from one another ($P = 0.40$). During PM hours, INC and DEC calves had very similar average rectal temperatures (38.88 ± 0.02 and 38.89 ± 0.02 respectively), which was significantly different from CON (38.82 ± 0.02; $P < 0.05$). A study by Huber et al. (1984), higher rectal temperatures were associated with higher milk levels. Another study did not see any differences in rectal temperatures between different levels of milk replacer (Khan et al., 2007).

Respiration rates were also found to be significantly impacted by milk replacer levels ($P < 0.01$). Calves on DEC had significantly greater AM respiration rates then CON ($P < 0.05$) and INC ($P < 0.01$) (35.94 ± 0.51, 34.14 ± 0.51, 33.64 ± 0.51 breaths/min, respectively). However, CON and INC were not significantly different from one another ($P = 0.34$). The DEC calves (42.44 ± 0.93 breaths/min) also had the highest average PM respiration rates, though only significantly different ($P < 0.01$) from INC (39.62 ± 0.93 breaths/min). Respiration rates for CON (40.00 ± 0.89) were not significantly different from either DEC (42.58 ± 0.89; $P = 0.07$) or INC (38.77 ± 0.89; $P = 0.30$). Overall respiration rates were lower in the AM than PM. Respiratory evaporative cooling takes place and allows for the lowest values to appear around midnight (Berman, 1968). When calves were feed different levels of milk, there was no difference in respiratory score (Kehoe et al., 2007; Khan et al., 2007). Depending on the intensity of panting, panting may increase maintenance requirements up to 25% (NRC, 1981).

There were no significant differences among health of the calves due to levels of milk replacer: fecal score ($P = 0.10$), scours ($P = 0.75$), respiratory ($P = 0.40$), or fever ($P = 0.40$), with no significant differences between milk replacer groups. Though increased levels of milk replacer have traditionally been thought to increase fecal score, this was not found to be the case in this study, which agrees with others feeding calves elevated levels of milk replacer (Huber et al., 1984; Jasper and Weary, 2002; Kehoe et al., 2007; Khan et al., 2007). However, increase fecal scores were reported in other incidences, which could be related to feeding increased protein levels (Brown et al., 2005; Hill et al., 2006).

When evaluating performance solely on weight gain, NHS had higher ADG than HS; but for milk replacer level, there was no significant difference in ADG. However, DEC calves consumed less feed, indicating they were able to gain weight comparable to the other groups. This difference may be the result of a more developed rumen or better feed efficiency potential which may eventually result in a difference over time. There was a trend ($P < 0.10$) for DEC to have a different overall feed efficiency from INC. Also, varying levels of milk replacer may have a greater impact during initial weeks of life, during pre-ruminant and early ruminant stages. There appears to be common patterns between the housing and milk replacer groups (Table 4). Both feed and water were inversely related for housing and milk replacer groups. Highest averages for feed consumption were for NHS and CON and these had the lowest averages for water, while

HS and DEC consumed lowest quantities of feed but consumed the highest levels of water.

Table 4. Estimated mean feed and water consumption.

Treatment	Feed	*P*-value	Water	*P*-value
HS[1]	1.10 ± 0.05	< 0.01	$3943.28 \pm 98.51_{a}$	< 0.01
NHS	1.71 ± 0.05	< 0.01	$2228.28 \pm 97.96_{b}$	< 0.01
CON[2]	$1.57 \pm 0.06_{a}$	< 0.05	$2576.05 \pm 221.36_{a}$	< 0.01
INC	$1.36 \pm 0.06_{b}$	< 0.05	$3022.69 \pm 221.36_{ab}$	< 0.01
DEC	$1.32 \pm 0.06_{b}$	< 0.05	$3591.33 \pm 221.37_{a}$	< 0.01

[1] Housing treatment groups. HS= Heat Stress and NHS= Non-heat stress housing environments
[2] Milk replacer treatment groups. CON= Constant milk replacer level (1.1% BW in milk replacer); INC= Increasing milk replacer level (1.2% BW in milk replacer to 1.5% adjusted weekly); DEC= Decreasing milk replacer level (1.5% BW in milk replacer to 1.2% adjusted weekly).
*Within responses in treatment group, means with different subscript letters are significantly different ($P < 0.05$).

For physiological responses, DEC consistently had the highest values with INC having the lowest responses, except for AM rectal temperatures. In the housing level, HS had the highest values for all physiological responses, except for AM rectal temperatures. This may demonstrate the importance of dissipation of heat accumulated either from metabolic heat or from the environment which appears to take place in the evening hours. Overall, heat stress and milk replacer levels appear to impact growth and physiological responses in neonatal dairy calves, with differences in housing being more pronounced.

CHAPTER IV

CONCLUSION

Based on the observations, heat stress and milk replacer levels affect performance and physiological responses of neonatal dairy calves. Though both tested variables influenced the neonatal calf, heat stress environment may have a greater influence on performance by decreasing growth parameters because of physiological adjustments made to heat stress. Calves which were not exposed to elevated THI levels were able to perform better in terms of weight gain. These calves also consumed more feed but less water. The calves housed in heat stress conditions demonstrated responses to stress in terms of elevated rectal temperatures and respiration rates. These elevated responses demonstrate an attempt to alleviate body heat.

Levels of milk replacer also influenced physiological responses in calves. Though milk replacer levels did not result in differences in weight gain, there was a difference in amount of feed and water consumed. This could potentially influence rumen development and post-weaning performance. It may reflect the ability to utilize increased levels of milk replacer during the pre-weaning period. More research is needed to understand long term effects of milk replacer levels.

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